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A PERSPECTIVE ON ACQUISITION OF NASA SPACE SYSTEMS

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December 1992

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The purpose of the work documented in this annotated briefing was for IDA to understand NASA's unique acquisition process (as opposed to DoD's), develop preliminary outcomes for space-related programs in terms of cost and schedule growth, and explore issues related to improving methods for estimating costs and schedules of space acquisition programs. IDA's initial findings concerning cost and schedule outcomes for NASA programs over the past thirty years show that manned programs generally show more cost growth then unmanned programs and high schedule growth is associated with high cost growth. Overall, NASA space programs have demonstrated enormous technical success; however, these successes take considerably more time and money than comparable DoD programs.

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INSTITUTE FOR DEFENSE ANALYSES

Independent Research Program

PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) under the Independent Research Program. The objective of the task was to understand the NASA acquisition process and to develop cost and schedule outcome measures for NASA and other space-related programs.

This work was reviewed within IDA by Bruce R. Harmon and Joseph W. Stahl. Discussions with NASA personnel were of benefit to this effort. In particular, we wish to thank David Pine and Joanna Gunderson of Code B, Comptroller, Headquarters, and Joe Hamaker of the Marshall Space Flight Center.

CONTENTS

INTRODUCTION AND DEFINITIONS

Objective

- Understand the NASA acquisition process
- Develop cost and schedule outcome measures for NASA and other space-related programs
- Explore issues, perform analyses, and present results

Over the past three decades, major U.S. space programs have required significantly greater time and funding to complete than originally planned. Major overruns in these areas tend to erode congressional and administration support for these programs. Research at the Institute for Defense Analyses (IDA) has shown that ratios of actual to planned costs and schedules are extremely useful measures for Department of Defense (DoD) decisionmakers. Knowing how different management strategies affect the outcomes of completed programs allows DoD to emulate the most successful strategies and to avoid less successful ones. IDA has evaluated the impact of such initiatives as prototyping, design-to-cost, and multi-year procurement on cost and schedule growth in weapon system programs, including satellites. Also, knowing the extent of such experience by equipment type is useful in planning. National Aeronautics and Space Administration (NASA) programs tend to have more nonrecurring development activities and less recurring production activities than defense programs. Systematic analyses of past outcomes for NASA and other space-related programs are not, however, readily available to NASA managers.

Therefore, IDA initiated a Central Research Project to:

- Understand the unique features of the NASA acquisition process. These include the relationship between NASA Headquarters and the Centers, technical, schedule, and cost risk, mission requirements, and equipment types.
- Develop cost and schedule outcome measures for NASA and other space-related programs. Appropriate methods for measuring the outcomes for widely diverse projects that have experienced considerable scope change need to be developed.
- Explore issues, perform analyses, and present results. Analysis needs to be targeted toward providing information that will assist NASA in improving cost- and schedule-estimating methods and management practices.

Definitions

- NASA Acquisition: Development and production and operations planning of aeronautical and space systems
- Space System: A collection of integrated components to achieve a specific purpose beyond the earth's atmosphere, such as earth observation or planetary exploration
- Acquisition Process: Steps taken by NASA HQ, Centers, and contractors to acquire space systems

NASA spends over 80 percent of its budget on purchased goods and services. Much of this spending is for the acquisition of space systems.

NASA acquisition, as we define it, encompasses the development and production and the planning for operations of aeronautical and space systems. The current research focuses on space systems. The process of acquiring these systems is a time-consuming and complex one, involving NASA Headquarters, the NASA Centers, and contractors.

THE NASA ACQUISITION PROCESS

The NASA Acquisition Process

- Policy History
  - Goals
  - Program Planning

- Acquisition Process Today
  - Budget Process
  - Acquisition Strategy
  - Program Review Process

The discussion of the NASA acquisition process covers two major areas, history and the process today. In the historical section, we describe the evolution of the acquisition process over time, including the structured program planning system and budget trends. Next, we describe the decisionmaking process as it is today, including budgeting, acquisition strategy, and program review.

History of NASA Acquisition Policy

- Early Years (1958–1961)
  NACA had focused on aircraft technologies (1915–1958)
- Institutionalizing the NASA Acquisition Process (1962–1965)
- Years of Maturity (1965–1986)
  Budget Cycle—long trough
- Planning for NASA's Future (1986–present)
  Challenger crisis

There are four major eras of NASA acquisition policy:

- The early years (1958–1961), when NASA was created from NACA. During that time, NASA and the rest of the government were refining their acquisition policies.
- A period of institutionalization (1962–1965), when NASA began to develop a more tightly defined structure for acquisition, as it moved into the Apollo Program.
- Years of maturity (1965–1986), when, following the lunar landing, the NASA budget declined substantially. The acquisition process continued to evolve, and problems in the process were studied.
- Years of planning for the future (1986–present), in which the Challenger accident caused schedule delays in NASA programs, and federal budget constraints are putting pressure on NASA to crystallize the missions of its programs and to improve acquisition management practices.

Early Years [illegible]

- WWII increased level of government contracting
- "Space race" gave NASA freedom to define acquisition practices
- NASA negotiated CPFF contracts often without competition
- Cost overruns and delays occurred

The history of NASA contracting evolved along with the rest of government contracting. The World War II experience was a great influence, as the government did much more contracting than it had in the past. Government agencies wanted access to the great capabilities of the private sector [2].

Because of the pressure to procure items quickly, the Department of Defense and other government agencies began to waive formal advertising in favor of negotiated contracts. The 1950s campaign to close the missile gap with the Russians created a model upon which NASA could draw in setting its own acquisition practices.

The Air Force, charged with closing the missile gap, used a high degree of concurrency in acquisition. Basic and applied research, vehicle and component design, the development of production facilities, and the design and test of launch facilities went on simultaneously. The Air Force decided not to use the traditional arsenal system, which the Army used to develop the Jupiter rocket. Instead, while the Air Force had responsibility for the success of its programs, it used contractors in every phase of research and development. In many cases, such as the Bomarc missile and the B-58 bomber, the Air Force hired a prime contractor, which selected subcontractors and performed testing and integration. In its ballistic missile programs, the Air Force hired its own component contractors and also hired a systems integrator. Thus, many of the issues that NASA had to face in development and production of space systems had already arisen in DoD programs, especially the Air Force's Atlas and Titan intercontinental ballistic missiles. NASA initially followed the Armed Services Procurement Regulations of 1947 with minor modifications.

The "space race" created a similar atmosphere of urgency for NASA. The massive Apollo program began in 1961 with President John F. Kennedy's speech that identified the goal of putting a man on the Moon within the decade.

This urgency gave NASA considerable freedom in defining acquisition practices. Major issues that NASA (and other agencies like DoD and the Atomic Energy Commission) struggled with included: What is the appropriate role of contractors in defining and building systems? If the government delegates responsibility to the contractor, how can the government provide technical direction? Should government or the private sector integrate the system? NASA had the capability to do its own integration for some systems and often used it.

In 1961, NASA reaffirmed the principle of contracting out for research and development (R&D). The largest contracts were negotiated and often were not competed. For example, McDonnell Douglas won the contract for the Gemini spacecraft because of its experience with Mercury. The two systems were similar, and McDonnell Douglas could get going quickly. McDonnell Douglas also received a contract for ten improved Delta launch vehicles without competition, since NASA found that developing another source would have cost $10-20 million more and delayed the launch schedule by 18-30 months.

The R&D contracts NASA awarded were generally cost plus fixed fee (CPFF) contracts. The contractor was awarded a fee based on a percentage of the cost estimated at the beginning of the contract. Because research and development is risky, NASA bore the cost of overruns. The only penalty to the contractor for overrunning a CPFF contract was that no fee was awarded on the overrun—all costs, however, were fully covered.

This style of R&D quickly caused problems. Enormous resources went into developing proposals for NASA, because, once a contractor won a competition, that contractor virtually could not lose money. Profit under a CPFF contract is not tied to performance, so the government had little leverage once a contractor was selected. NASA began to experience large cost overruns and schedule delays in its development programs, mainly because of the technological advances sought in space systems and the inadequate definition at the start.

Institutionalizing the NASA Acquisition Process
[illegible]

- Government-wide task force addressed:
  - essential government role in management and technology
  - greater use of fixed-price and incentive-type contracts
- NASA worked to maximize competition, switch to incentive contracts
- Hilburn Task Force highlighted problem of inadequate definition of work

As a result of problems in the 1950s, the 1960s were a time of change in federal acquisition practices. There were several task forces put together to study acquisition problems. A presidential task force headed by Budget Director David Bell addressed the issue of appropriate roles for government and the private sector. In April 1962, the task force said that there were certain functions that should never be contracted out. Full-time government officials should decide "the types of work to be undertaken, when, by whom, and at what cost" [3]. The task force also recommended that federal agencies use their own labs to maintain knowledge of the most advanced science and technology, implying that there should be less reliance on contractors. To promote this increased federal role, the task force recommended more federal "supergrade" slots for scientists and engineers, along with guidelines for avoiding conflicts of interest. Another recommendation to avoid overruns was greater use of fixed-price and incentive contracts.

In response, NASA intensified its efforts to maximize competition before contract execution, then use performance and cost reduction incentives. NASA underwent a series of adjustments in the 1962–63 period during which existing major contracts were converted from CPFF to incentive contracts.

In 1964, some of NASA's largest projects were in serious trouble. Delays plagued the Apollo Program, which had to develop a launch vehicle, three spacecraft modules, and ground support equipment. Components that worked well individually failed when incorporated into a system. It was unclear who was responsible for integration of the Apollo Program. In addition, many programs had cost overruns, and there were several launch failures. Congress pressured NASA Administrator James E. Webb for action. Deputy Associate Administrator Earl Hilburn was assigned to study available methods of schedule and cost estimating. His task force concluded that the largest cost overruns were due to incomplete definition of work at the start. NASA took steps to bring programs under greater control by revising its contract with the Jet Propulsion Laboratory, pressuring the Centers to tighten project monitoring, and proposing a system of Phased Project Planning (PPP) similar to that in use at the DoD.

Years of Maturity (1965–1986)

- Formal Phased Project Planning established October 1965
- Project Approval Document required for systems (1968)
- Post-lunar-landing programs oriented toward user application and funding
- 1981 Hearth Committee assessed NASA project management
- Space shuttle mission/turnaround shortfalls
- Challenger accident put space program on hold for 2-1/2 years

Although NASA had in some sense been engaged in phased planning for some time, an October 1965 directive put PPP into practice by establishing four phases in the life of a project: advanced studies (Phase A), project definition (phase B), design (Phase C), and development and operations (Phase D). The directive was vague in relating PPP to the budgetary and procurement cycles and in several other areas, like the dividing lines between the phases, the role of the program offices, and the procedure for performing advanced studies. In addition, the 1965 directive mandated full competition at every stage in the process, a mandate program offices regarded as impractical. They continued to follow traditional practices of limiting competition for a phase contract to contractors who participated in the preceding phase.

Final guidelines for PPP issued in August 1968 alleviated some of these problems. However, the 1968 guidelines were only part of a system by NASA Administrator Webb to consolidate and centralize resource planning and program review. Each phase would be covered by a Project Approval Document (PAD), which authorized the program office and its field installations to proceed and to let contracts. Phase A was designated preliminary analysis and Phase B definition. Phase A was supposed to be done in-house, while Phases B and C were to be done under fixed-price or CPFF contracts. Development and operations (Phase D) were to be done under incentive contracts.

NASA funding peaked in the early 1960s, then plummeted to a level less than half the peak in the early 1970s. Funding after that was relatively stable in constant-dollar terms.

In the 1970s, reduced funding meant increasing emphasis on project management. An internal NASA group, the Hearth Committee, assessed NASA project management in 1980–81. Its mission was to identify generic reasons that aggravate cost and schedule growth. The main reasons for cost and schedule growth included technical complexity, inadequate definition of the program goals, a tendency to accept unrealistically low contractor bids, and poor tracking of contractor performance. While some specific recommendations for additional review activity were made, the general recommendations emphasized the application of existing techniques for project management, with top management commitment and monitoring. The committee said that the technical complexity made a certain amount of growth inevitable and recommended that NASA nevertheless continue to pursue complex technologies. The committee identified the costing of ground facilities as a particular problem, along with the schedule and cost problems caused by interdependency due to the parallel development of critical supporting systems.

The space shuttle, intended to be a quick-turnaround system, experienced performance shortfalls. The cost and schedule overruns on the shuttle diminished support for other NASA programs. In 1986, the Challenger accident shocked the nation and resulted in a hold for manned space launches. Some payloads associated with these manned launches had to be modified to go on expendable launch vehicles. The space community had time to reflect on the causes of the tragedy and to improve safety procedures; however, several programs suffered from the delay.

Planning NASA's Future (1986–present)

- Budgeting struggles
  - Growth in 1986–1991
  - Budget may grow by less than inflation in future
- Augustine Commission
  - What is NASA's mission?
  - How to design acquisition process to perform mission?
  - Budget projections now regarded as optimistic
- Cost-estimating issues
  - Contractor buy-ins
  - Interaction of budgetary and cost estimating processes
  - Schedule and performance consideration
- Contract type issues
  - Award fee vs. other types
  - Government/contractor liability

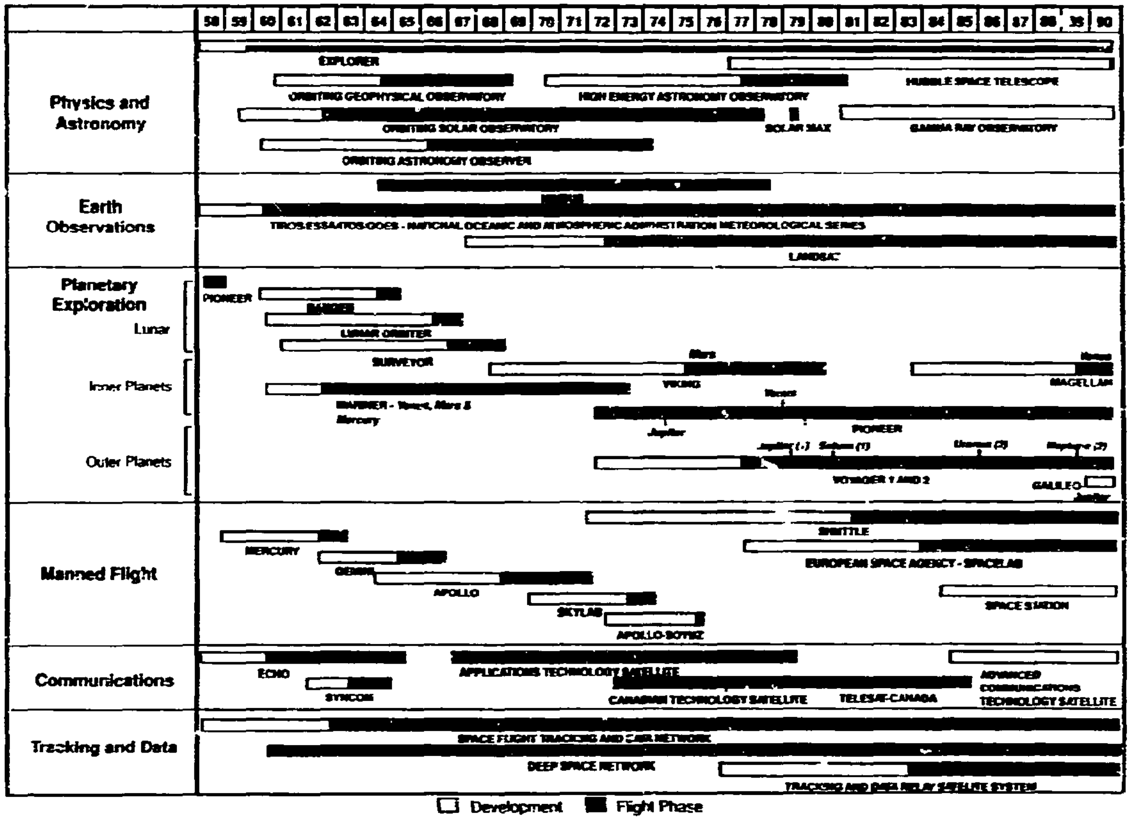
The budget is a key issue for the future. In the 1986–91 period, there was some growth in the NASA budget, but that growth is not expected to continue.

In 1991, the Augustine Commission worked to suggest an appropriate mission for NASA and to discuss how to design an acquisition process to perform that mission. Since the Commission report [4], the budget climate has worsened, so Augustine's budget projection recommendation of 10 percent annual real growth is highly unlikely.

Another issue that affects NASA acquisition is cost estimating. The level of effort devoted to the cost-estimating function and how it should be performed are key questions. The cost analysts at NASA are responsible for maintaining and improving the historical cost and programmatic data base, for building and improving cost models and tools, for developing independent government cost estimates and preparing non-advocate review estimates, for supporting trade studies, for performing cost risk analyses, and for monitoring contractor cost estimates. Cost overruns in major programs such as the space station, shuttle improvements, or large space science projects affect related programs as well. For example, the grounding of the shuttle due to the Challenger accident raised costs in many NASA programs [5]. Schedule and performance considerations need to be considered and traded off in light of costs. The problem of how to eliminate contractor buy-ins in the current budget climate is another issue.

Finally, contract types are a recurring issue. In 1991, the Government Accounting Office (GAO) surveyed contract-level cost and schedule growth at NASA's four largest procurement centers—Goddard Space Flight Center, Marshall Space Flight Center, Kennedy Space Center, and Johnson Space Center. The GAO found that one in every three contracts in the sample experienced cost increases and more than 40 percent experienced schedule growth. Somewhat surprisingly, fixed-price contracts had higher cost growth than other types. Research and development contracts experienced a lower annual rate of cost growth than service contracts. The GAO noted that NASA's centralized database did not have the capability to track contract cost and schedule growth, although the capability could possibly be added [6]. NASA has been urged to reduce the prevalence of award fee contracts and to award more contracts on an incentive fee or fixed price basis. In addition, the liability of contractors and the government for defects in systems or accidents is a matter of concern.

Civil Space Program: Major Projects



Source: Reference [4].

The civilian space program as managed by NASA has pursued a variety of major projects since its inception. While the manned flight programs have received the most attention, NASA has pursued projects in science, communications, and earth observations as well.

In the area of physics and astronomy, Explorer was the first in a series of over 70 scientific satellites, including the Orbiting Solar Observatory and the High Energy Astronomy Observatory. In the 1960s, unmanned lunar exploration and exploration of closer planets such as Venus, Mars, and Mercury was emphasized, while missions in the 1970s have begun to explore the outer planets.

In areas of applied science, a series of earth observing programs began in 1960 with TIROS and have provided us with valuable meteorological information. The National Oceanic and Atmospheric Administration (NOAA) has taken over responsibility for meteorological satellites, and such information is now virtually taken for granted. Communications satellite technology has evolved from NASA's Echo I, launched in 1960, to spawn a whole industry.

Many of these applications tend to have flight phases that are long relative to their development times. Another distinctive feature of the civil space program is the tendency to build on successes by following up, for example in the area of satellites, with a new or modified satellite.

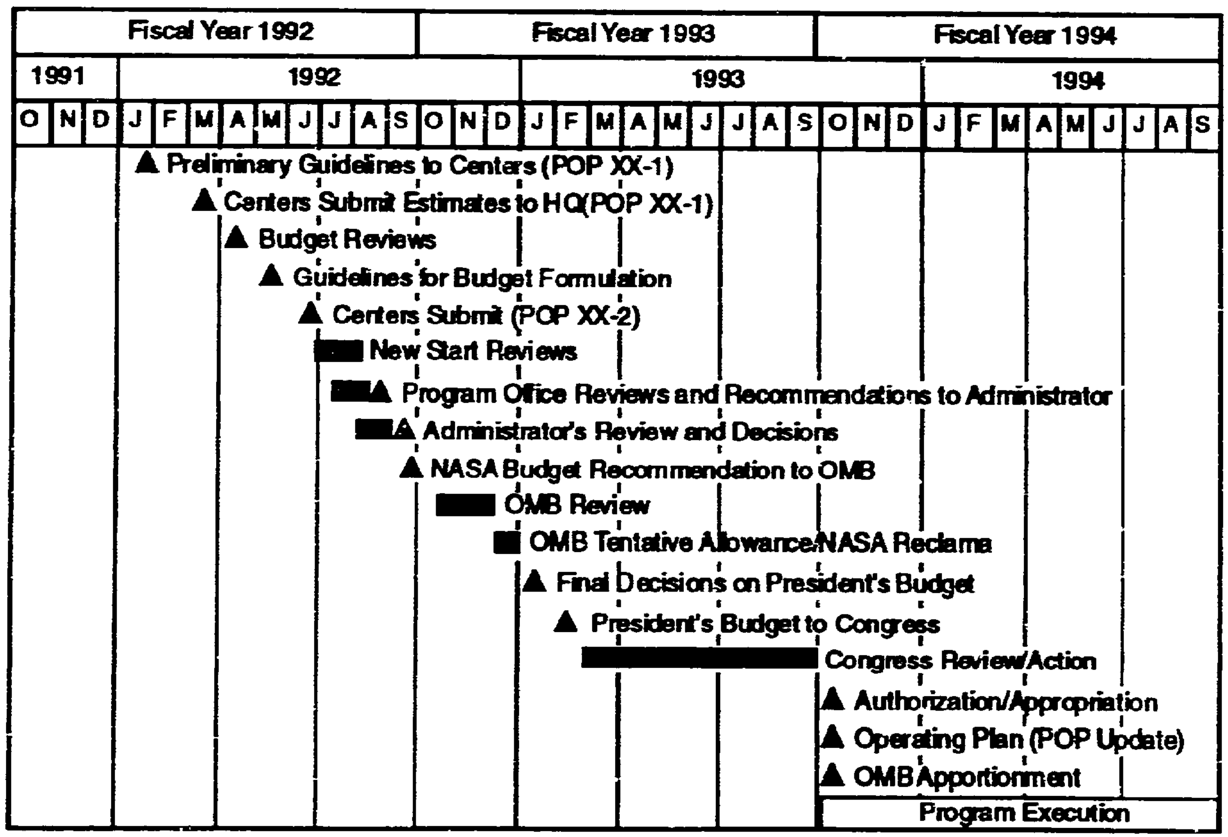
NASA Budget

Billions of 1992 Constant Dollars
30
25
20
15
10
5
0
1959
1964
1969
1974
1979
1984
1989

Funding for NASA began modestly. At its founding in 1958, NASA was the follow-on to the National Advisory Committee for Aeronautics (NACA), an organization that was doing aircraft technology research for military and commercial aircraft. As NASA acquired additional missions, funding built up to nearly $30 billion (1992 dollars) in the mid-1960s, during the Apollo Program when Americans landed and walked on the Moon. At this point, the U.S. was devoting roughly 4.5 percent of the federal budget and about 0.8 percent of the gross national product to NASA.

During the late 1960s and early 1970s, the NASA budget underwent a steady decline as the Apollo Program ended, reaching a steady state of around $10 billion from 1974-1986. Since 1986, NASA funding has grown to around $15 billion, which represents about 1 percent of the federal budget, or slightly more than half its peak level of the mid-1960s.

NASA Budget Schedule



NASA receives annual funding from Congress, and its planning works on an annual basis. There is a rolling process that takes roughly three years to complete [1]. The budget for fiscal 1994, for example, would be formulated beginning in early 1992 after OMB has issued general guidelines. The centers would submit budget estimates to headquarters in March. In the first half of the year, NASA would conduct its Program Operating Plan (POP) and Institutional Operating Plan (IOP) exercises and would then submit a preliminary NASA budget to the OMB. Reviews of new start programs are conducted during the summer. A final NASA budget would be submitted to OMB in early October 1992. The OMB and the administration would then make their changes to the budget, and the result would be included in the budget that the President submits to Congress in January 1993.

Thus, at a given time, there are three sets of activities: execution of the current fiscal year's budget, enactment of the next year's budget, and formulation of the following year's budget.

Congress then reviews and revises the budget. Congress passes bills authorizing NASA to obligate funds and appropriating those funds. While the process is supposed to result in a final approved budget by the beginning of the fiscal year (October 1, 1993 for fiscal 1994), this is not always the case. In recent years, controversy over particular spending items in the federal budget has often delayed the passage of final bills past the start of the new fiscal year. In such cases, Congress typically allows government agencies to operate in a "steady state" under a continuing resolution.

Because of the annual funding process, there is a *de facto* control gate for acquisition programs at the beginning of each fiscal year. Uncertainty about future funding is a fact of life. Unstable funding for a program, however, can greatly increase the costs and delay the accomplishment of major acquisition programs.

- Technologies and inventions ill-defined at start
- Technological complexity
- Tight time schedules
- Unique or small-quantity systems
- High availability and mission life requirements

Many of the challenges faced by NASA in acquiring systems are also faced by the Department of Defense in acquiring weapon systems. An important common feature is that, for the most part, we are talking about inventions. NASA is noted for being an R&D agency and is expected to be at the leading edge of technology. The acquisition process often begins before the "thing" that is being acquired has been invented, or even defined in detail. The process can begin with a vague goal, such as "a rocket booster powerful enough to send man to the moon" but without a specific notion of what the characteristics of such a booster would be.

The above example also points up another characteristic of the NASA acquisition process—technological complexity. By the nature of its mission, NASA must use very complex technology to build its systems.

In addition, tight time schedules are a common feature. These schedules occur because of national security issues or because of the need to meet a launch window or constrain cost.

All of these characteristics are shared with the DoD. However, there are several characteristics that NASA does not share with the DoD. For example, only one or only a few of a particular system are built. The NASA systems also have unusual availability requirements—often greater than DoD systems. A military aircraft typically flies a sortie of around two hours. The aircraft must be available and foolproof during the sortie—however, it can be repaired and maintained on the ground. A satellite in space—whether NASA or DoD—often must be available 24 hours a day, and repair in space is very costly. Therefore, system developers must ensure availability through an appropriate combination of high reliability and redundancy of components.

Phased Development of NASA Projects

Typical Duration	1-2 YRS	1 YR	1-3 YRS	> 4 YRS
Phase Title & Function	Pre-Phase A "Feasibility" • What should be done? • Can it be done with current foreseeable technologies?	Phase A "Preliminary Analysis" • How should it be done? What are the options?	Phase B "Definition" • Which option gives best value for money and fits the NASA program best?	Phase C/D "Design Development" • Develop system within the budgeted cost and in the promised timeframe
	• Preliminary Science Justification • Technical Feasibility • Identification of Technical Developments • "Back-of-the-Envelope" Cost and Schedules	• Refine justification, define requirements • Identify program and project options • Identify high risk technical elements • Start technology development of these elements • Refine Cost/Schedule estimates	• Refine scientific justification and requirements • More detailed definition of Option Designs, Technologies, Inheritance, Cost, Schedules • Technical studies of High Risk Elements • Accurate Cost/Schedule estimates (Basis of NASA Budget Request)	• Refine Design and Development Plan • Design and development of selected option • Procurement of Subsystems • Manufacture, Assembly • Test and Verification • Launch • Initial Operations
Documents for Next Phase		Project Initiation Agreement, Preliminary Project Plan RFP for Competitive Phase B	Definition Review, Project Plan Approved, Level 1 Requirements document Approved, MOA's/MOU's Approved, RFP for Development Activities	

Source: NASA

The NASA project cycle consists of a categorization of all project activities into distinct phases, separated by control gates at which go/no-go decisions are made. These phases are:

Phase A—Preliminary Analysis

Phase B—Definition

Phase C/D—Design, Full-Scale Development, Operation [7].

"All systems start with the recognition of a need or the discovery of an opportunity and proceed through various stages of development to a final disposition" [1]. Before the formal process begins, there is a period of time, typically 1-2 years, of feasibility study.

The pre-Phase A activity may take as little as 3-6 months for a fast-track program, or as long as 10 years for a slowly-evolving program. The Phase A preliminary analysis typically lasts around 1 year and produces a project initiation agreement, a preliminary project plan, and an RFP for Phase B work. During Phase A, the options for achieving the goal are identified. Phase B lasts 1-3 years and involves identification of the best option. During Phase B, the project plan and the Level 1 requirements document are typically approved. Phase C/D is the longest phase and usually takes at least 4 years. The purpose of Phase C/D, is to develop the system within the budgeted cost and in the promised time frame. This phase also encompasses manufacturing, testing, and initial operations of the system.

NASA sometimes uses contractors, usually with competition, in Phases A and B. Contractors are usually employed sole source for Phase C/D, which is very complex.

COST AND SCHEDULE OUTCOME MEASURES

Cost and Schedule Outcome Measures

- Summary of Data Available
- Demographic Data
- Schedule Data
- Cost Data

This section discusses the data we have collected on NASA and other space programs. It includes demographic, schedule, and cost data.

Approach to Data Collection

- Data
  - Drew heavily on IDA space library
  - NASCOM, GAO, previous IDA work, Space Directory
  - Beginning to use NASA sources (briefings, archives)
- Format
  - Three sections
    - Demographics
    - Schedule
    - Cost
  - Comments and sources for each section

The raw data in the database we compiled came primarily from IDA's library of space-related publications. Specifically, sources included the Marshall Space Flight Center's NASA Cost Model (NASCOM), several GAO reports, data collected for related IDA work, the Interavia space directory [10], and several NASA briefings concerning recent programs.

We used a three-part format to organize the data we collected. "Demographics" describes the program, the user, and the producer. "Schedule" contains dates of program start, design reviews, delivery, and launch. The "Cost" section lists, where possible, each program's planned and actual costs, along with the planned and actual quantities. Each section also has its own comment field and a field that records the source of the data.

Types of Data Available

85 Programs Total

Demographics		Schedule		Cost	
Fields	N	Fields	N	Fields	N
Design Life	58	ATP	63	Date of Plan	16
Type	82	PDR	41	Planned Development Cost	27
User Type	84	CDR	39	Planned Quantity	19
Application	79	Delivery	37	Planned Operations Cost	4
User	79	Planned Launch	30	Date of CE	8
Agency	72	CE Launch	76	CE Development Cost	51
Contractor	77	Planned End	6	CE Quantity	29
		CE End	6	CE Operations Cost	5

N = Number of programs with data available

Each type of data was divided into a number of fields, defined as follows:

- Demographics:
  - Design Life: The stated design life of the system, in months.
  - Type: Code for type of mission: 1-Communication/Navigation, 2-Earth Observing HIGH (>10,000 nautical miles), 3-Earth Observing LOW (<10,000 nautical miles), 4-Solar Observation, 5-Other Astronomical, 6-Earth Fields/Particles, 7-Planetary flyby, 8-Planetary (or Solar) orbiter, 9-Planetary lander, 10-Manned
  - User Type: Code for type of user: 1-Civilian, 2-Military, 3-Commercial
  - Application: Brief description of mission
  - User: Name of user or operating agency
  - Agency: The agency responsible for developing the system
  - Contractor: The prime contractor
- Schedule
  - ATP: Date of Authority-To-Proceed or program Go-Ahead
  - PDR: Date of Preliminary Design Review
  - CDR: Date of Critical Design Review
  - Delivery: Date of first delivery of a system
  - Planned Launch: Development Estimate of the launch date
  - CE Launch: Current Estimate of the launch date (or actual)
  - Planned End: Development Estimate of the end of the program
  - CE End: Current Estimate of the end of the program (or actual)
- Cost
  - Date of Plan: The date on which the quoted Development Estimate was made
  - Planned Development Cost: Development Estimate of the Development Cost
  - Planned Quantity: Development Estimate of the Quantity
  - Planned Operations Cost: Development Estimate of the Operations Cost
  - Date of CE: The date on which the quoted Current Estimate was made
  - CE Development Cost: Current Estimate of the Development Cost
  - CE Quantity: Current Estimate of the number of spacecraft in the program (or actual, if program complete)
  - CE Operations Cost: Current Estimate of the Operations Cost

Numbers of Demographics Cases

By Type	N
Communication/Navigation	21
Earth Observing (>10 K nmi)	4
Earth Observing (<10 K nmi)	11
Solar	2
Other Astronomical	6
Earth Fields/Particles	13
Planetary—Flyby	8
Planetary—Orbiter	5
Planetary—Lander	3
Manned	9
Not Categorized	3

By User Type	N
Civilian	55
Military	20
Commercial	7
Other	3

The largest type group is communications (21), which includes all three user types—for example TDRSS-1 (a tracking and data relay system for NASA), DSCS-2 (a communications satellite for DoD), and the Intelsat series (communications satellites for Intelsat). The database also includes 13 systems such as the Gamma Ray Observatory for monitoring earth fields. There are 7 manned programs, because some parts of Apollo, such as the linear module, are considered separately.

Almost two-thirds of the programs are for civilian use. There are 20 military programs, and 7 (including the Intelsat series and Landsat) are for commercial use.

Definitions for Usable Cost and Schedule Growth Data Points

- **SCHEDULE means data for ATP *and* planned launch *and* current estimate of launch were available**
- **COST means data for planned cost *and* actual cost were available**
- **BOTH means data for COST *and* SCHEDULE were available**

We defined a usable *schedule* data point as a program for which we had an ATP date, a planned launch data, and actual launch date. Similarly, a usable *cost* data point is a program for which we could find a planned and an actual cost. *Both* refers to those points that meet the criteria for both cost and schedule.

Schedule growth was defined as the difference between the actual schedule duration (ATP to launch) and the planned duration, expressed as a percentage of the planned duration, (i.e., (Actual–Planned)/Planned]. Cost growth was defined analogously as the difference between the planned and actual costs, expressed as a percentage of the planned cost. In calculating cost and schedule growth, no adjustments were made for quality change or scope change in the program.

All costs were adjusted to 1992 constant dollars by using the NASA New Start Inflation Index.

Programs With Both Schedule and Cost Growth Data (16 Programs)

Program	Schedule Growth	Cost Growth
LANDSAT-A	10%	89%
Magellan	24%	84%
SMS-1	26%	133%
Mars Observer	32%	83%
UARS	40%	0%
OSO-8	43%	64%
AE-C	47%	16%
HEAO-A	71%	21%
ACTS	74%	40%
GRO	78%	205%
EUVE	86%	200%
Spacelab	113%	233%
HST-OTA	117%	88%
HST-SSM	142%	200%
Galileo	195%	157%
Ulysses*	151%	-16%

* Major scope change affected outcome.

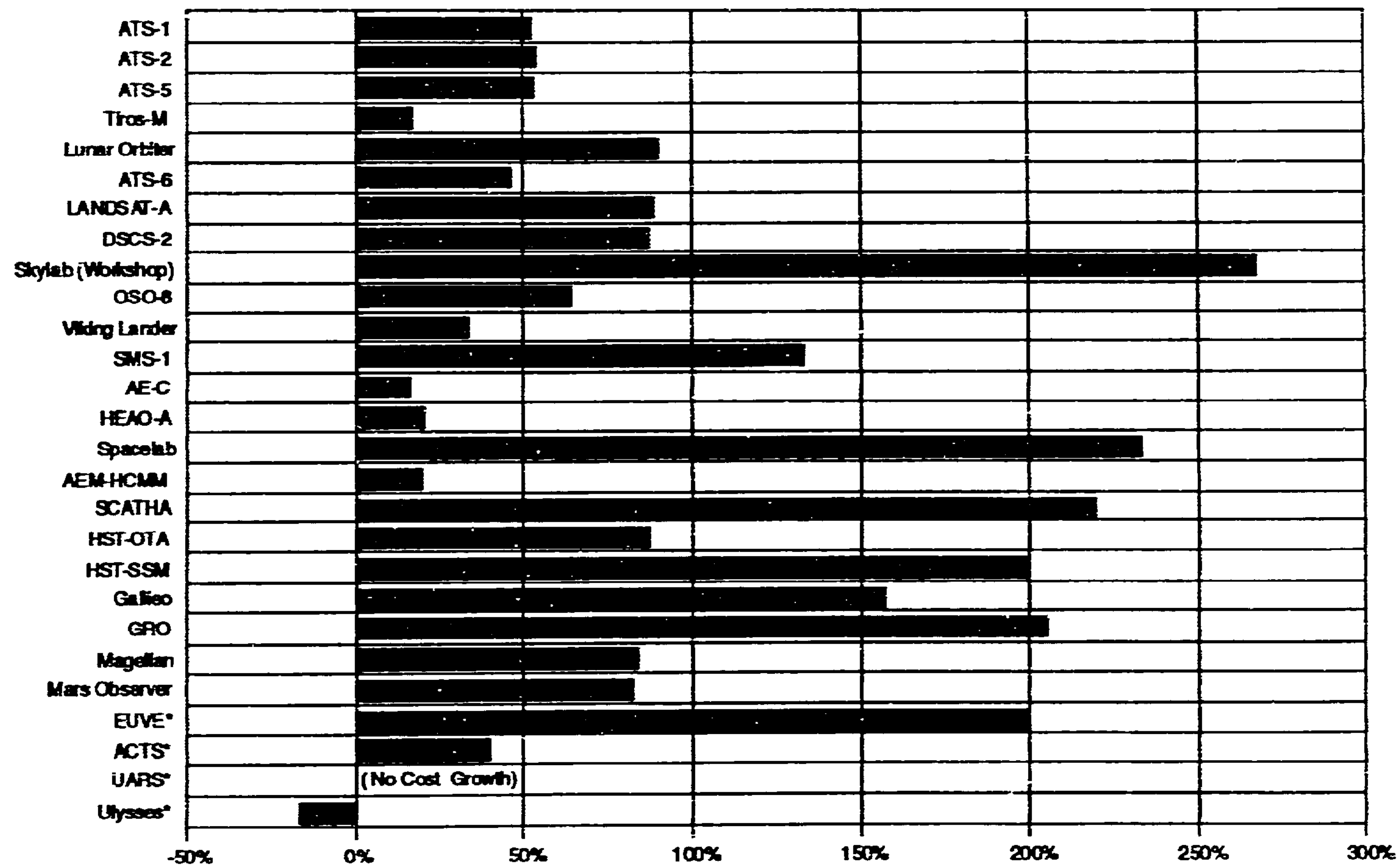
Listed above are the 16 programs in our data base with sufficient data to calculate both cost and schedule growth.

Programs With Only Schedule (9 Programs) or Cost Growth Data (12 Programs)

Program	Schedule Growth	Cost Growth
Mariner 5	2%	
DE-1	23%	
DE-2	23%	
ERBS	36%	
Ranger	49%	
Orbiter	58%	
Gemini	71%	
Surveyor	117%	
Mercury	151%	
Tiros-M		17%
AEM-HCMM		20%
Viking Lander		34%
ATS-6		47%
ATS-1		53%
ATS-5		53%
ATS-2		54%
DSCS-2		87%
Lunar Orbiter		90%
SCATHA		220%
Skylab (Workshop)		267%

In addition, our sample included 9 programs with data on schedule growth only, and 11 programs with data on cost growth only. While we make no claim that this is a representative sample, the outcome measures can be calculated for a mix of very small and very large programs and a variety of equipment types.

Cost Growth

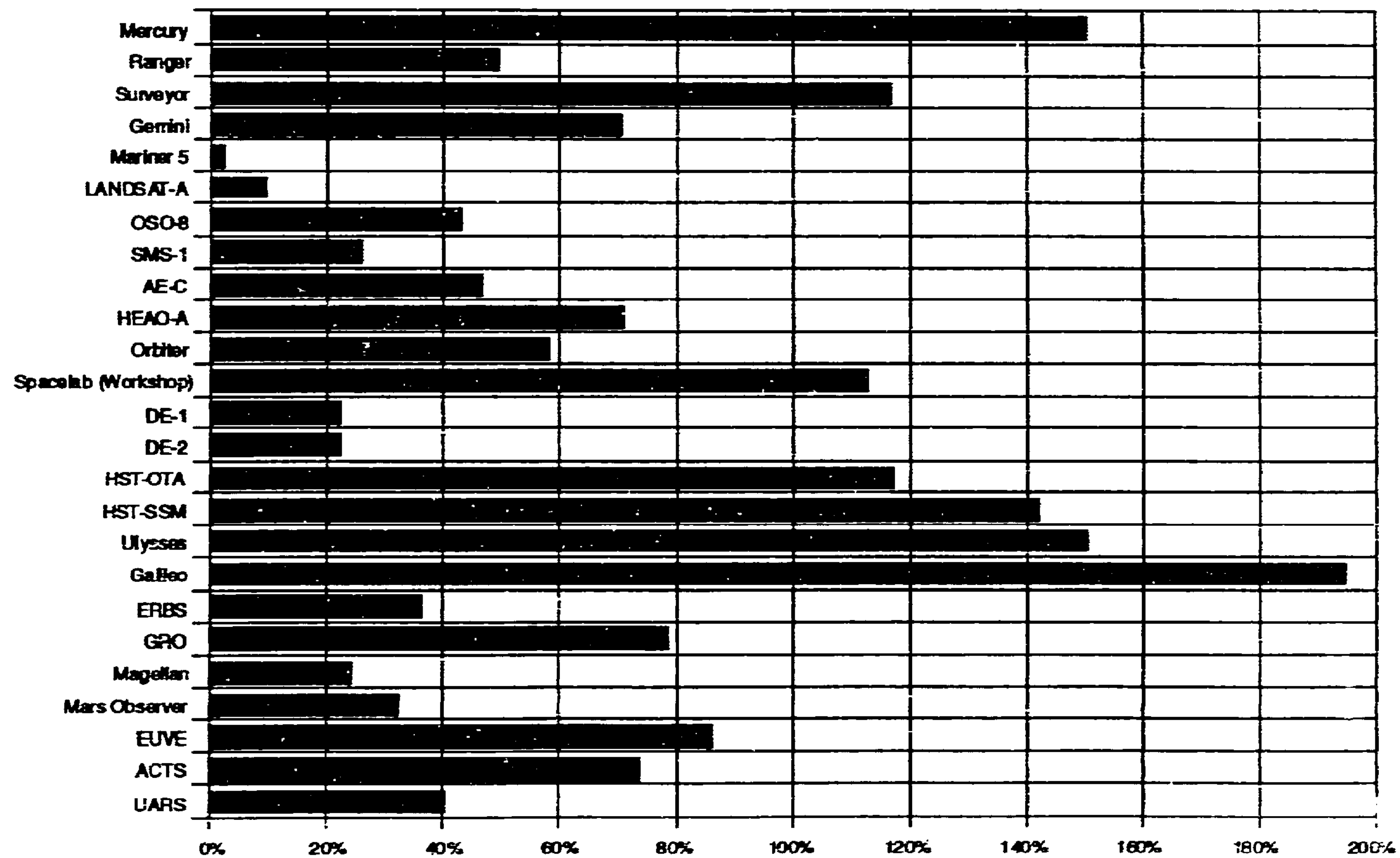


* Programs not includ in averages.

Generally speaking, those programs for which we could gather data on both planned and actual cost experienced significant cost growth. All had positive cost growth except Ulysses, which was significantly cut in mid-program, and UARS, which apparently enjoyed relative stability and little or no cost growth.

Several programs were excluded from calculations of aggregate statistics. EUVE, ACTS, and UARS were excluded because we only had data on relative growth and not on absolute size. Ulysses was also excluded because of its peculiar history of scope change. For the remaining set of 23 programs, we found an average cost growth of 101% and a weighted average cost growth of 110%. The individual observations in this set ranged from 16% to 267%.

Schedule Growth



All 25 programs for which we could calculate a planned and actual schedule exhibited some positive schedule growth in the period between ATP and first launch. The individual magnitudes ranged from 2% to 195%, with an average of 71%.

ISSUES, ANALYSES, AND RESULTS

Issues, Analyses, and Results

- **Substantive Issues**
- **Measurement Issues**
- **Analyses**
- **Summary**

This section discusses the issues that have arisen from our initial exploration of the NASA acquisition process and outcomes.

We discuss the substantive NASA management issues we have discovered, some measurement issues that need to be resolved, show some illustrative analyses, and summarize the results of the central research project.

Substantive Issues

- Identify patterns of cost and schedule growth by:
  - NASA era
  - Size
  - Type
  - Scope Change
  - Length
  - Technical complexity
  - Contractor
  - Management initiative
  - Acquisition approach

- Identify which management initiatives are associated with more favorable outcomes
  - Contract type
  - Prototyping
  - Government involvement (e.g., labs)
  - Prime and sub arrangements

A number of useful analyses can be performed on the data we have gathered, and others could be performed on a more extensive and comprehensive data base.

- NASA Era. It would be useful to know whether NASA experienced more cost and schedule growth at specific times in its history.
- Size. Large programs may be more difficult to manage and thus experience more cost and schedule growth. Multiple centers and contractors may experience difficulty coordinating their efforts. However, it is also possible that larger programs are more carefully managed because of their high public profile. In the DoD, larger programs tend to experience less cost and schedule growth.
- Type. Certain classes of systems may experience different levels of cost and schedule growth.
- Scope Change. As previously indicated, changes in scope can cause changes in costs and schedules. It would be useful to analyze these changes more systematically.
- Length. The same issues and questions about program size also pertain to length: Does a long program have more cost and schedule risk, or is it more likely to have room for error?
- Technical complexity. The level of planned and actual technical complexity affects cost and schedule outcomes. Measuring the amount of advance over the current state of the art is a technique that illuminates this relationship.
- Contractor. Individual contractors may have policies and practices that improve cost and schedule outcomes. Some government customers include a contractor's past cost and schedule record as a formal criterion for awarding contracts.
- Management Initiative. NASA's management practices may influence cost and schedule growth.
- Acquisition Approach. NASA centers have varying acquisition strategies. The Marshall Space Flight Center, for example, has a Science and Engineering lab that keeps pace with its major contractors. The Goddard Space Flight Center does less hands-on work. Different centers also favor different forms of contracts. It would be interesting to see if these varying strategies are associated with different cost and schedule outcomes.

Management strategies need to be identified more systematically. We have identified several specific approaches—including prototyping, multi-year procurement, design-to-cost, and dual-sourcing—that have been used within the DoD. In NASA, formal management initiatives such as design-to-cost have been used less often. Nevertheless, there have been some initiatives that were designed to improve program cost and schedule outcomes. For example, different types of contracts were used depending upon the needs of the program. There has been prototyping, particularly at the subsystem level. The government/contractor division of labor varies from program to program and is another factor that needs to be correlated with program outcomes.

Measurement Issues

- How to treat different versions—when is it a new program?
- How to treat scope and quantity changes when calculating outcome measures
- How to establish uniformity in cost data
  - Level of cost: contract, program, or budget
  - Year dollars (sometimes missing)
- How to define schedule intervals
  - ATP is best start date—sometimes not available
  - Delivery may be better end date than launch
- How to define and measure management initiatives to make them most useful

Among the measurement issues we have encountered in this work are:

- How to treat different versions of a program. Some programs start a new version because the first one was unsatisfactory, while others are following up with new technology. When to declare a new program with a new baseline is a key measurement issue.
- How to treat scope and quantity changes when calculating outcome measures. Program management often makes changes in scope and quantity when it is clear that the budget does not permit all goals to be achieved. Measuring cost growth in isolation from scope change can obscure the true outcome. For example, we put the Ulysses program in a separate category because, while it came in under its planned cost, its scope was substantially narrowed. This is one way of handling the situation. Another is to calculate a measure of scope change and include it along with cost and schedule growth information. Yet another is to adjust cost growth explicitly for change in scope. For quantity change, IDA has developed a technique to adjust cost growth in weapons programs for changes in the planned quantity. Because the quantities of space systems are typically low, it is not clear that this technique is appropriate. Some additional development work may be necessary to determine how to treat this issue.
- How to establish uniformity in cost data. We investigated a number of sources for cost data. Sometimes cost data was at the contract level, sometimes at the program level, and sometimes at the budget level. In some cases, the source did not identify the level of the data. The data we used is at the program level, in general. It might be useful at some point to expand the database to include work breakdown structure (WBS) level data. (This would, however, be a sizable undertaking due to the lack of standardization of WBS elements.) Another problem of uniformity was that sources did not always specify whether the costs were given in current or constant dollars or, if in constant dollars, what year dollars.
- How to define schedule intervals. The Authority-to-Proceed (ATP) date was the starting point in this database, but it was not always available. We used launch date as the end of the program, because it was the date most readily available. However, systems are delivered some time before launch, and launch dates are often constrained by weather and planetary alignment. Therefore, delivery date may be preferable.
- How to define and measure management initiatives to make them most useful. We have proposed measures of management initiatives but have not yet begun to identify them at the program level. In doing this, we should keep current issues and controversies in NASA acquisition in mind.

Possible Causes of Cost and Schedule Growth in NASA Systems

- Requirements not well-defined at Phase C/D start
- Technical sophistication and the acquisition process
- Underestimation of difficulty, followed by scope growth and external impacts
- Schedule growth in one program can spill over and affect others
- Random events like Challenger accident have devastating impact

Several studies have speculated about the causes of cost growth in NASA systems, both in general and for specific systems. Some of them are touched on here.

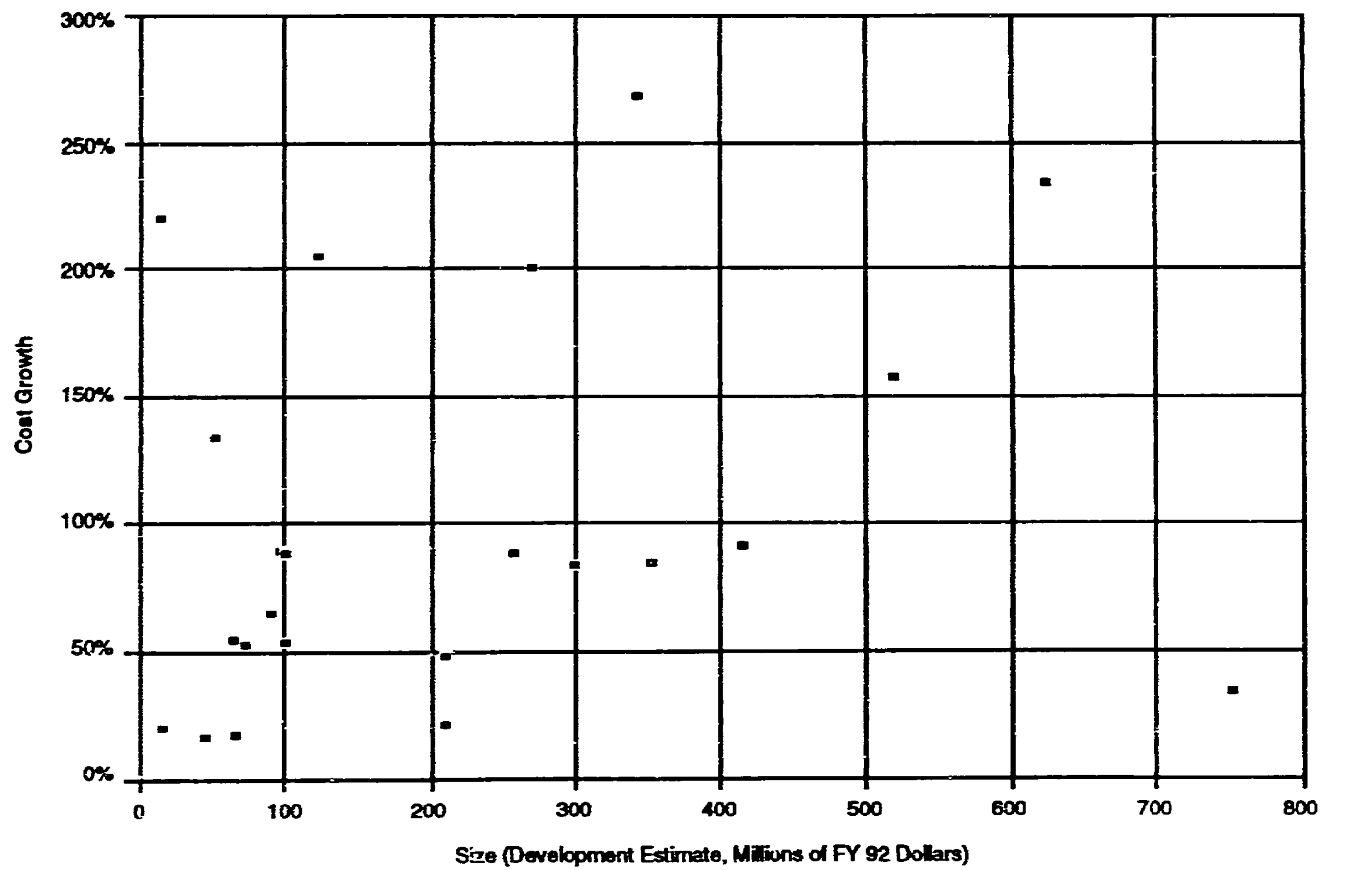
Perhaps the greatest problem remains that cited by the Hilburn study in the 1960s: incomplete definition of the work at the start.

A study of cost growth in NASA and in DoD found that the principal cause of NASA cost growth was system sophistication, while the secondary cause was the acquisition process [9].

According to the Hamaker study [10], the largest single cause is underestimation of technical difficulty. At least part of that underestimation is due to a failure to spend time and resources in early development phases. If budget is available, projects proceed rapidly to Phase C/D, sometimes too rapidly, while there is still substantial risk in the program.

A Congressional Budget Office (CBO) study found that schedule growth in one program can spill over and affect others [5]. A PRC study found that schedule stretchouts are caused by funding constraints, technical problems, external interfaces, and catastrophic events [11].

Space System Cost Growth by Program Size (DE)



If we look at cost growth as it relates to program size, we see that larger NASA programs experience more cost growth than small programs but the relationship is not statistically significant. (A possible explanation for the positive relationship is that there are more, better-developed cost-estimating tools available for smaller programs. Also, larger programs may present higher levels of technical and schedule risk.

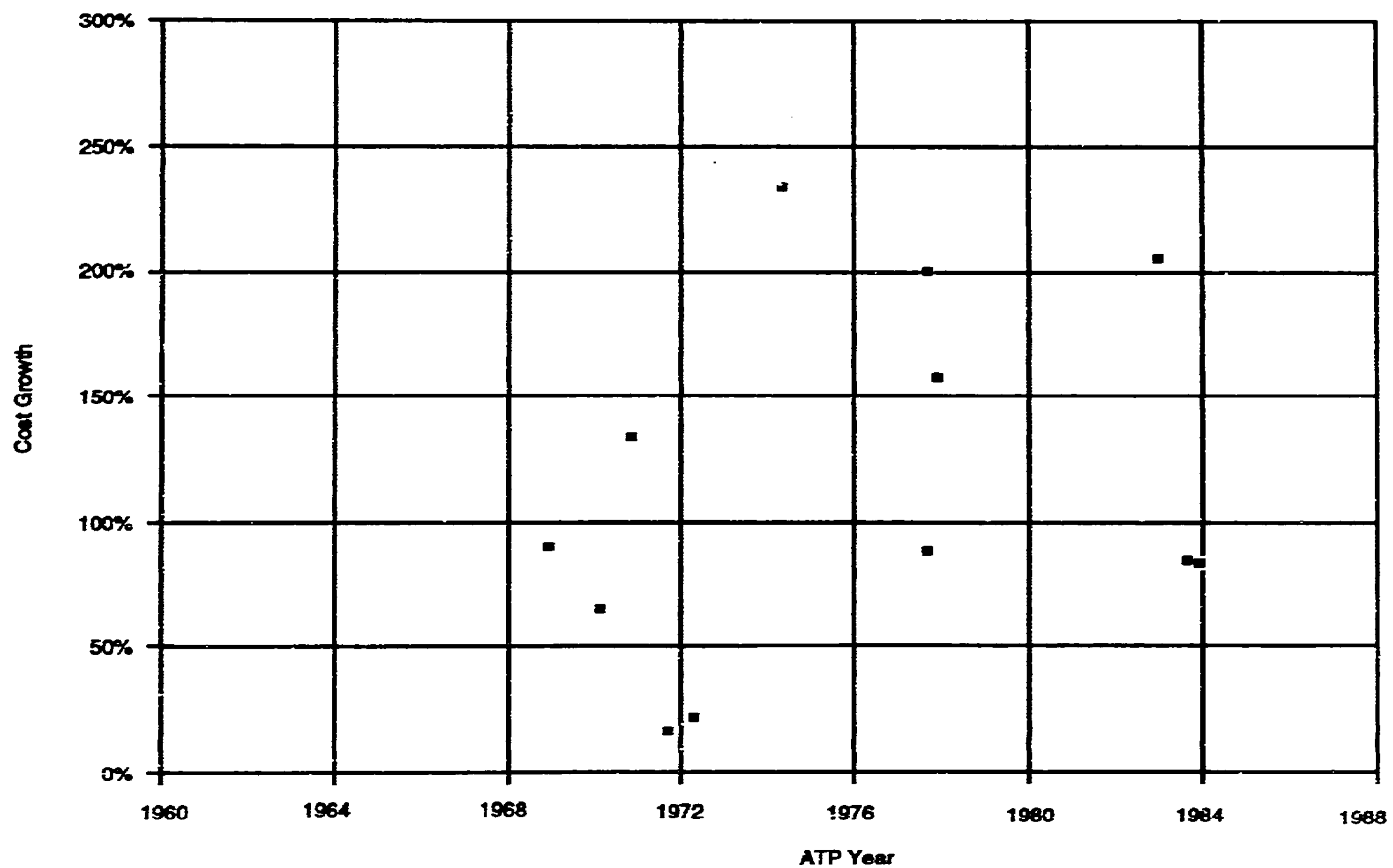
This result is the opposite of DoD experience. IDA has found that small DoD programs tend to experience more cost growth than larger programs [12]. Large programs may tend to be glamorous and carefully managed in order to maintain support for them, while smaller programs may receive lower priority.

Among the NASA programs we examined, there is a significant (.03) positive relationship between *schedule* growth and program size. The regression result is:

Schedule Growth (in percentage units) = 28.3 + 0.19 × Development Estimate (millions of 1992 dollars)

Standard error of the coefficient = .0758   Adj. R^2 = .32.

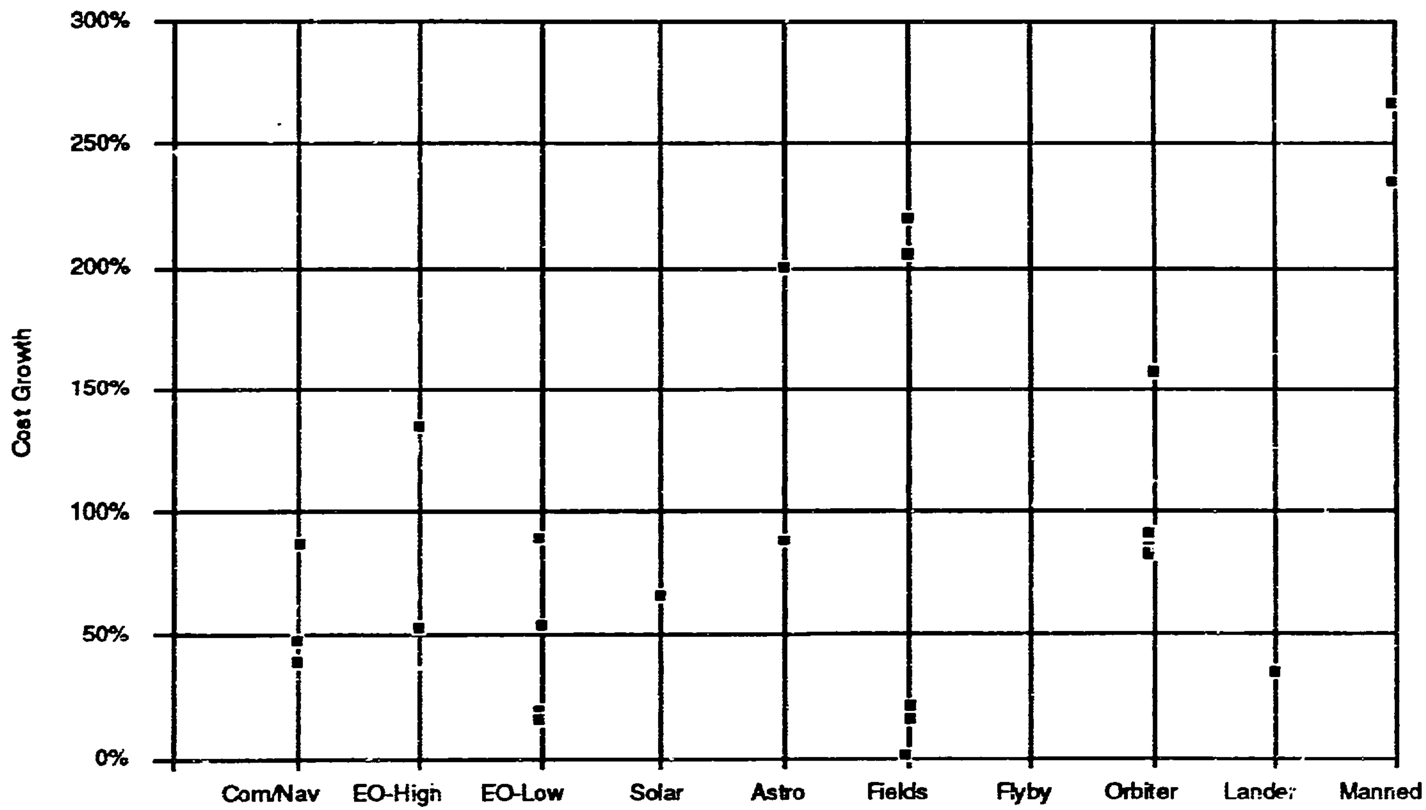
Space System Cost Growth by ATP Year



NASA programs that began in the mid- to late 1970s have experienced higher cost growth than earlier or later programs. For programs with ATP before 1970, average cost growth (weighted by actual costs) was 89 percent, while for programs in the 1970s, the average was 181 percent. For programs in the 1980s, average cost growth was 112 percent.

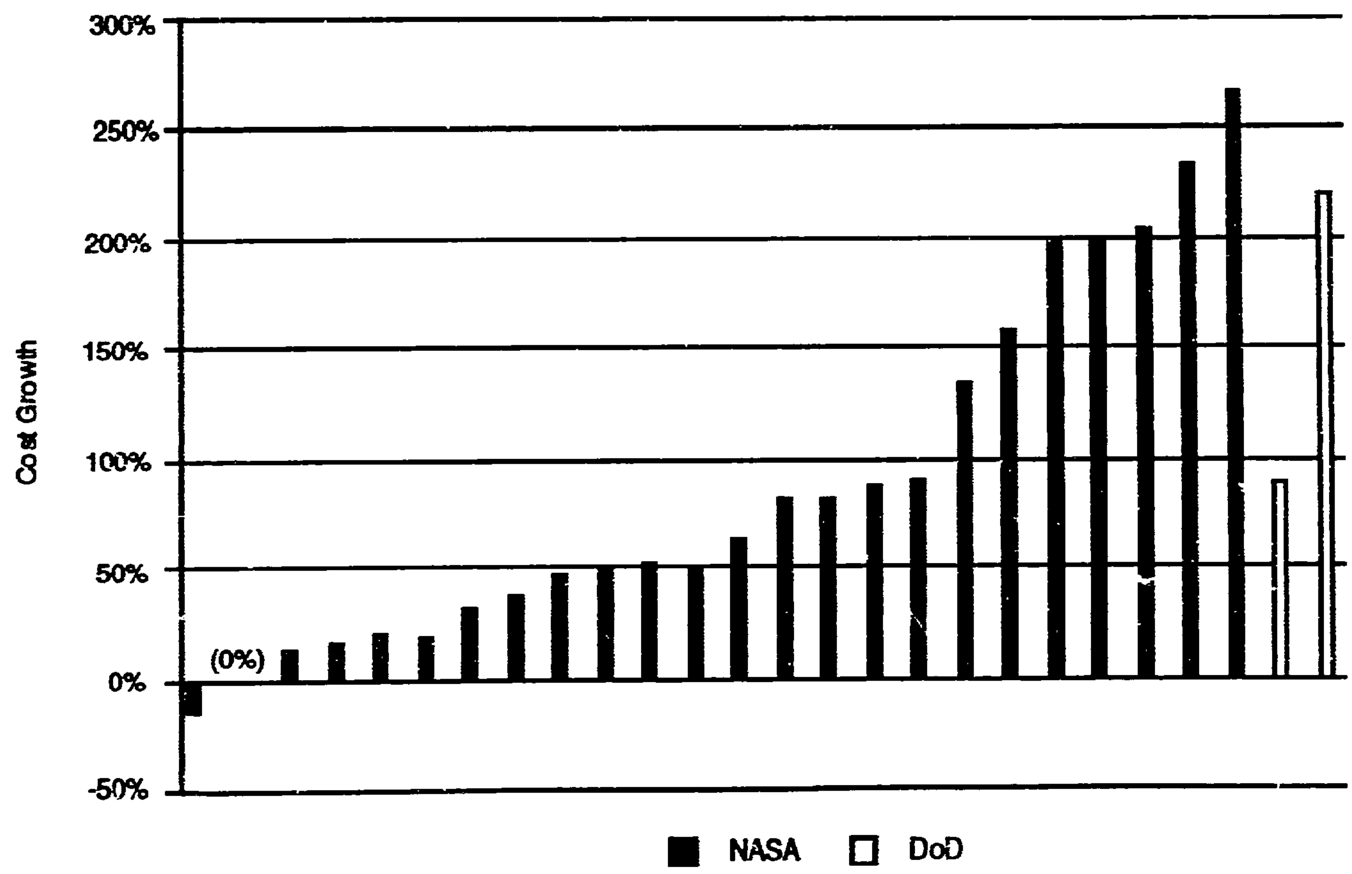
However, appearances may be deceiving with respect to the later programs. The stage of program completion is an important variable in cost growth analysis. On average, we would expect that a program that is only 25-percent complete would exhibit less cost growth than a program 75 percent complete, and a 75-percent complete program would exhibit less cost growth than a completed one. Cost growth tends to accumulate over time. As adverse cost experience occurs, estimates of the cost to complete a project are gradually revised upwards.

Cost Growth by Program Type



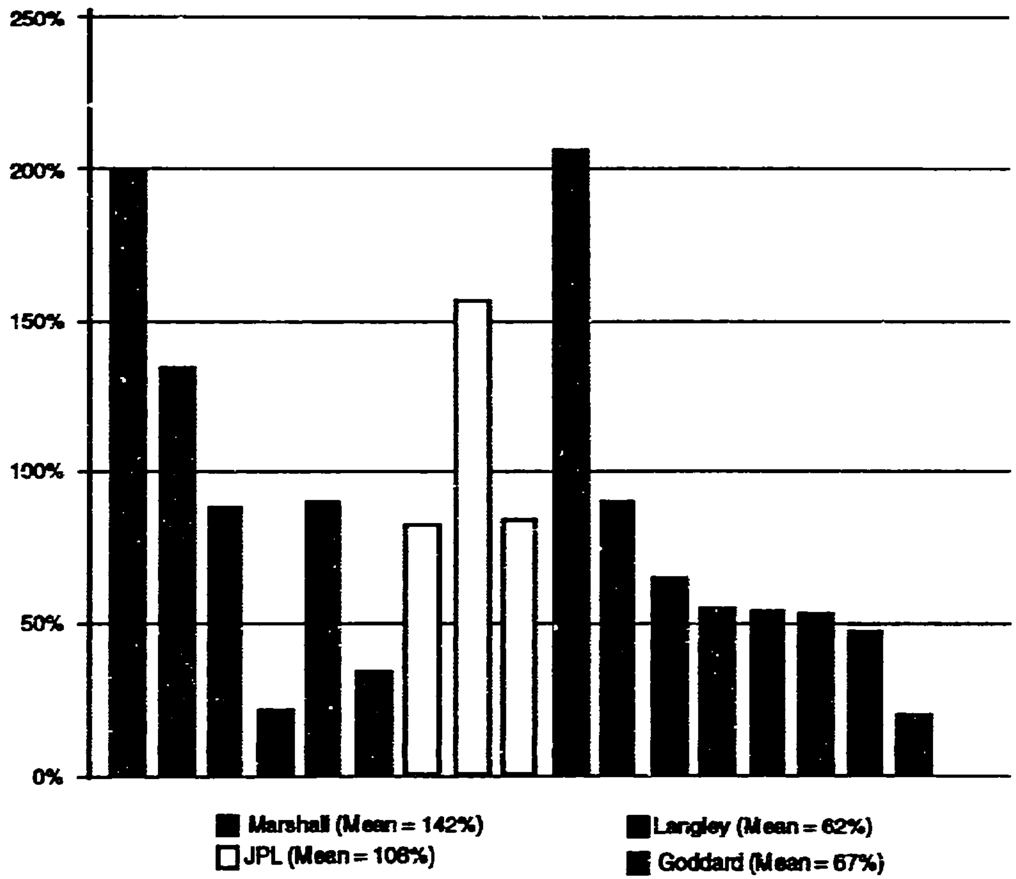
No clear patterns are seen when looking at cost growth by program type. Manned systems tend to grow more than unmanned programs. Fields programs exhibited mixed results, with two programs growing more than 200 percent, and three program with cost growth below 50 percent.

Cost Growth by User Type



The data were insufficient to do a rigorous comparison of NASA and DoD programs. The mean for the 24 NASA programs (unweighted by program size) was 95 percent, while the mean for the two DoD programs (DSCS-2 and SCATHA) was 154 percent. The difference between the two groups of programs was not statistically significant.

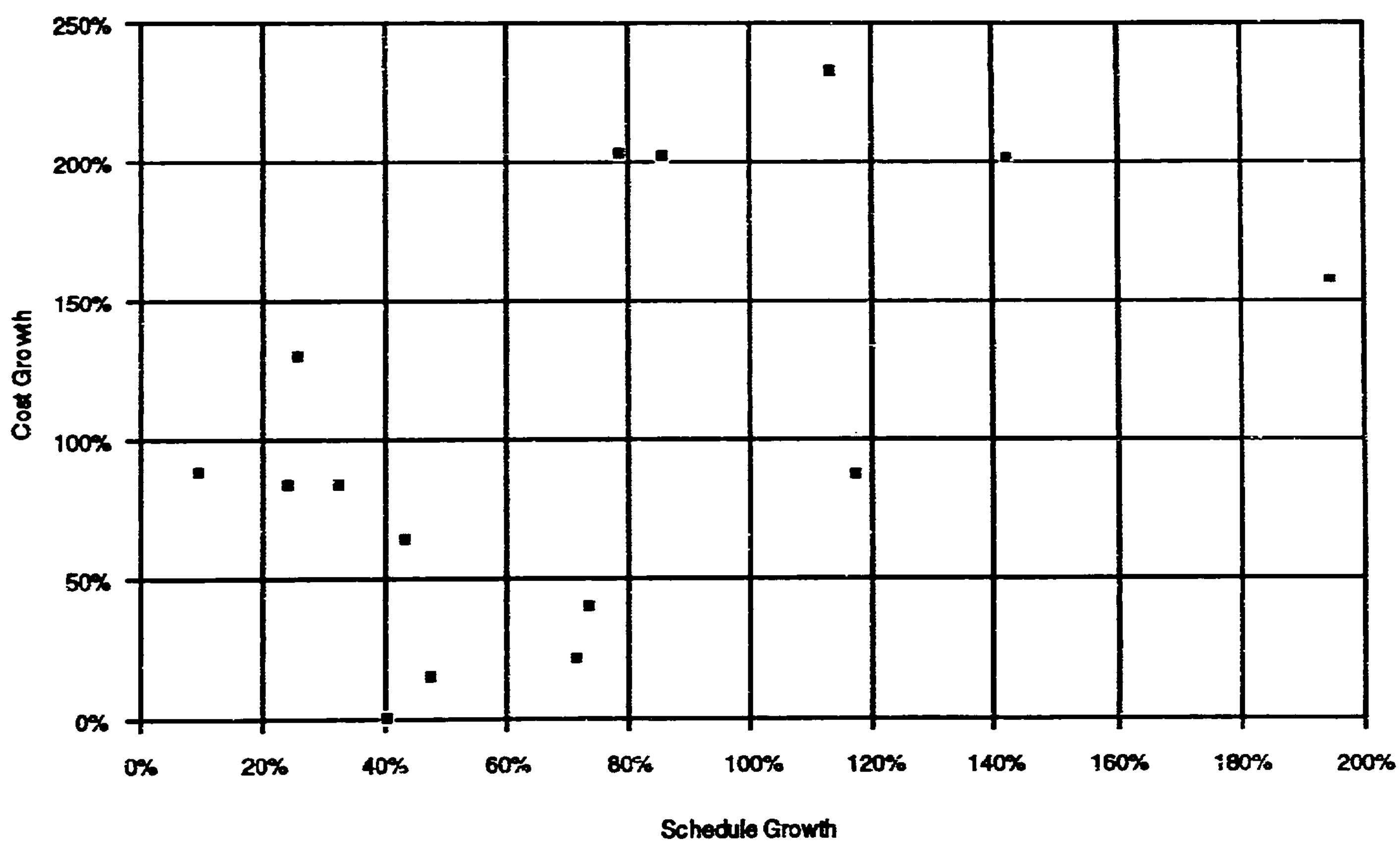
Cost Growth by Development Center



Note: Ulysses excluded.

Here, we look at cost growth as a function of the NASA Center that is developing the program. Programs developed at Langley had the lowest mean cost growth and programs developed at Marshall, the highest. However, the differences were not statistically significant. There is much variability in cost outcomes that does not seem to be explained by the Center involved in development.

Cost Growth Vs. Schedule Growth



There is a statistically significant positive relationship between cost growth and schedule growth. The regression results were:

Cost Growth = 0.52 + 0.76 × (Schedule Growth)

Standard error of the coefficient = .36 Adj. R^2 = .20

N = 15 (Ulysses omitted because of scope change).

SUMMARY

Summary

- Pilot effort indicates feasibility of measuring cost and schedule outcomes of NASA programs
- Little data on management initiatives; contract type and degree of contractor involvement are possible areas for future analysis
- High schedule growth associated with high cost growth
- Outcomes vary by system type-manned programs generally higher cost growth

The initial effort indicates the feasibility of measuring cost and schedule outcomes of NASA programs. The data we used were gathered from public sources. While there are still difficulties of measurement to be overcome, it should be possible to assemble a good database with NASA cooperation.

We have found little data on management initiatives within NASA. Data on contract type and degree of contractor involvement appear to be worth pursuing. In addition, the managing NASA center may be a useful proxy for management strategy.

Our initial analysis of the data indicates that high schedule growth is associated with high cost growth. Manned programs tend to experience higher cost growth than unmanned programs. Larger programs have significantly greater schedule growth than smaller ones. They also appear to have more cost growth, but this result is not statistically significant. There is no significant difference in cost growth by managing center or by time period.

The space systems acquired by NASA over the past three decades have achieved, for the most part, enormous technical success: Earth conditions are routinely observed from space, communication is revolutionized, the other planets in our solar system are much better known to us, and human beings have walked on the moon. Space systems are expected to be on the cutting edge of technology.

From a management standpoint, however, the record is poorer, considerably worse even than the DoD's experience. These technical successes have taken significantly more time and money than originally planned. NASA has recently asked IDA to undertake a study, Management Practices Case Studies, to understand and address these problems.

In this study, we took the initial steps toward developing measures of cost and schedule outcomes on a consistent basis. Such measures can be used to:

- Develop a system of management accountability in ongoing programs;
- Illuminate areas that require increased management attention (for example, by analyzing cost and schedule outcomes by type of program, contractor, or center);
- Provide a benchmark to evaluate past and future management strategies such as incentive contracting, subsystem prototyping, multi-year procurement, total quality management, and activity-based costing; and
- Identify which management strategies work consistently well and which are less effective.

New missions for NASA need to be defined to reflect the dollars available—inevitably, fewer than before. NASA will need a phased development process with a more disciplined approach to achieving cost and schedule goals in the future. NASA programs should continue to be on the cutting edge of technology, but achievement of these new missions in the current budgetary environment requires more; it requires tools for estimating both costs and schedules and management practices that are also on the cutting edge.

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ABBREVIATIONS

ATP	Authority-to-Proceed
CDR	Critical Design Review
CE	Current Estimate
CPFF	Cost plus fixed fee
DE	Development Estimate
DoD	Department of Defense
GAO	Government Accounting Office
IDA	Institute for Defense Analyses
IOP	Institutional Operating Plan
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OMB	Office of Management and Budget
OSSA	Office of Space Science and Applications
PAD	Project Approval Document
PDR	Preliminary Design Review
POP	Program Operating Plan
PPP	Phased Project Planning
R&D	research and development
RFP	request for proposal